The Class Act

DOE's Reservoir Class Program Newsletter

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Horizontal Drilling for Thermal Recovery in the Wilmington Field, California

by Donald Clarke, City of Long Beach, California
& Christopher Phillips, Tidelands Oil Production Co.

A potential 1.4 billion barrels of oil lies beneath greater Los Angeles in the Wilmington Field, but the cost of recovering the heavy 13° API oil is too high using conventional means. The City of Long Beach, Tidelands Oil Production Company, University of Southern California, and D. K. Davies Associates sought to improve the efficiency of steamflooding the Class III slope and basin clastic reservoir in order to expand operations and increase production.

With the help of the DOE, the partners succeeded–encouraging news for other operators hoping to decrease thermal operating costs in heavy oil reservoirs.

Laying the Groundwork

The successful plan called for detailed reservoir characterization, development of a 3-D deterministic model, drilling horizontal wells, and expanding the existing steamflood. The challenges of efficiently exploiting the remaining oil include studying steam-rock interactions, geostatistical modeling, reservoir simulation, and designing a predictive subsidence simulator.

During 1995 and 1996, the first two years of the project, well data dating from 1937 to 1994 were digitized and analyzed. This information required significant modification because of the wide range of data, age of data, multiple coordinate systems used, and subsidence.

In all, the stratigraphy from more than 700 wells was correlated. The data were predominantly SP and induction curves. The T and D sands of the Pliocene Tar Zone were subdivided, based on SP and resistivity response. Erosion within the T intervals and onlapping in the D intervals made facies boundaries difficult to determine.

An 18-layer deterministic geological model was constructed. This model was used to drill five observation wells, two horizontal injectors, and two horizontal producers. State-of-the-art mapping software was used to build a 3-D deterministic geological model.

Internal Compaction

Five temperature observation wells were drilled early in the project. The first well crossed the strata at predicted points, but three subsequent wells missed target depths by as much as 17 vertical ft. The targets sands total 60 ft thick, so a 17- to 20-ft error could result in missing the zone or a 30% loss of producing sands for gravity drainage. Using the information from the observation wells, the deterministic model was created before the horizontal wells were drilled.

Since 1937, internal compaction induced by oil withdrawal from the Wilmington Field has resulted in

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localized subsidence up to 29 ft. A study found that old well data were problematic and difficult to work with, but could be corrected and used along with new data to compensate for the intraformational compaction. The problem of intraformational compaction or induced subsidence affects several projects in the Wilmington Field and in other oil fields in California.

Making Data Adjustments

Figure 1 shows the components necessary for the subsidence corrections in the Fault Block II Tar Zone. These three components were used to alter the data:

1. Downhole adjustment–after the well was drilled
2. Adjustment for ground elevation changes
3. Internal compaction adjustment

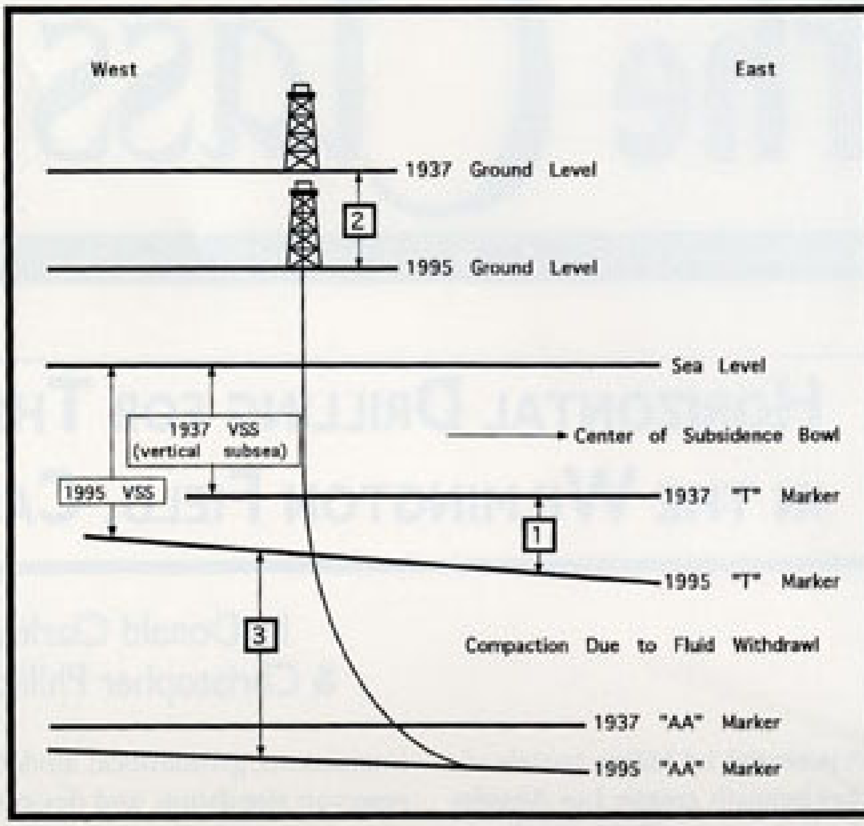

Figure 1 Three components of subsidence correction in the Fault Block II project:
1. Downhole adjustment for subsidence that occurred after the well was drilled—x, y dependent. Distance between 1937 and 1995 markers increases toward the center of the subsidence bowl.
2. KB elevation adjustment—operator dependent. Adjustment for subsidence before well is drilled.
3. Compaction of overlying sands.

Revising the Model & Maps

The deterministic model was rapidly revised. Then, new maps and cross sections were extracted from the model and supplied to the well planners, so the horizontal laterals could be located accurately in the target zone. The horizontal well plans traverse total subsidence contours from 12 ft to 22 ft. Figure 2 shows the horizontal well plans with four laterals under the City of Long Beach, California.

Geosteering

Calculations showed that each foot above the base of the D1D target sand effectively reduced recoverable reserves by 15,876 stock tank barrels. Accurate drilling required continuous good communication among the geologist, drilling superintendent, directional engineer, mud engineer, and log engineer.

Maps and cross sections extracted from the 3-D model were used to geosteer the drill bit. Geosteering involved locating the bit with respect to the upper horizons prior to drilling parallel to the bedding planes. Corrections for faults across the drilling path required accurate mapping and precise location.

Logging properties encountered in measuring the depth to the target sand, the D1D, are inherent in the equipment and allow for accurate geosteering. The deep induction reading tool (Rad) and the shallow reading tool (Rps) show a separation when the bit nears a shale. The deep reading tool response is suppressed first because the tool reads the shale. The shallow tool

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simultaneously reads the higher resistivity of the top of the D1D sand.

When drilling subparallel to bedding planes, the shallow tool induction has approximately a 24-in. depth of investigation, and the deep tool can read to 42 in. Geosteering within 3 ft to 4 ft of a lithology boundary is possible by monitoring the curve separation and reacting to the lithologic changes. These values are specific to the Tar Zone, but the technique will work in formations with known resistivity.

The intent was to stay above the base of the D1D sand using geosteering techniques to steer away from the D2 shale. Information and experience gained from the first well was used to meet this goal when drilling the remaining three horizontal wells in Fault Block II.

Results

Modern computer mapping tools have enabled geologists to map and remap very quickly and to design drilling target windows of less than 15 ft at depths of 2,300 ft for horizontal wells. The deterministic model which was developed is highly accurate and easily modified with new data.

Steam-assisted gravity drainage was initiated in the Tar Zone of Fault Block II of the Wilmington oil field in 1995. The experience gained from Fault Block II was readily transferred to Fault Block V, and plans are underway for expansion in both areas.

Five more horizontal steamflood wells were drilled into Fault Block V. The 15-ft-thick target window was reached, and instantaneous drilling rates of up to 600 ft/hr were attained using the geosteering techniques developed. All five horizontal wells are now undergoing cyclic steam stimulations prior to conversion to steamdrive operations.

Two horizontal wells in Fault Block V have been steamed and placed on production. The two wells average more than 200 barrels of oil per day (BOPD), compared to 16 BOPD before steaming operations. At the same time, the water cut decreased to 70%, compared to the average water cut before steaming operations of 95%.

The project has added 1,700,000 barrels of reserves to the Tar Zone, Fault Block pool. Forecasts place the peak annual production rates under steamdrive at 590 BOPD for the horizontal well project. Steam communication to the existing waterflood wells, from cyclic steam injection into two wells, has resulted in a six- to tenfold net oil production rate increase in the old waterflood wells.

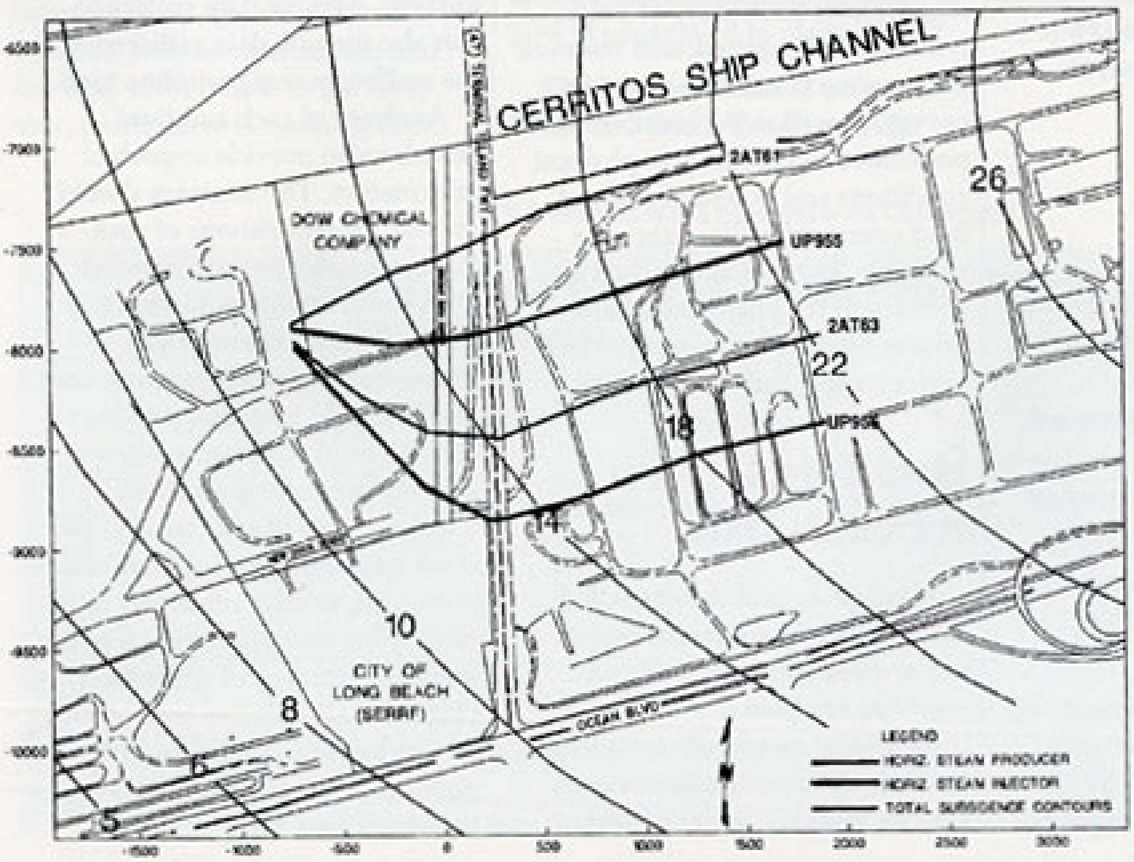

Figure 2 The horizontal well plans traverse across the total subsidence contours from 12 ft to 22 ft. To locate the horizontal laterals accurately, the operators had to modify the data and create a revised deterministic model before placing the wells.

Waterflood Optimization

by Michael Fowler, BDM Petroleum Technologies
& Viola Rawn-Schatzinger, BDM-Oklahoma

Waterflood optimization is an objective of several projects in the Department of Energy's Reservoir Class programs. The goal is to show how profits can be increased and reservoir life extended through improving oil recovery.

Waterflood optimization revolves around developing an understanding of the reservoir characterization model. This understanding forms the basis for identifying the significance of the oil recovery target, designing the best 3-D spatial arrangement of injection and extraction points, and strategizing the best combination of schedules and technologies for performing injection and extraction and for treating injection fluids and produced fluids.

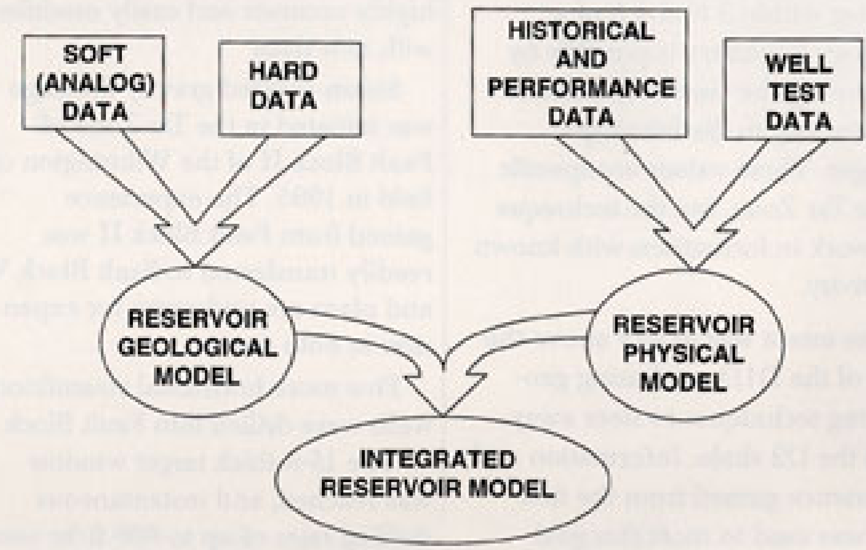

Figure 3 Components of an integrated reservoir model

The Integrated Reservoir Model

The "best" model for a reservoir merges two types of evidence in a mutually supportive way:

- Geological evidence represents depositional, diagenetic, and tectonic influences, and original fluid content of the reservoir
- Engineering evidence represents the physics of the reservoir system

The geological model is made up of both *hard* reservoir descriptive data and *soft* data obtained by observing geological analog deposits. The reservoir physical model incorporates the history of fluids removed and injected, and reservoir pore system conditions since discovery, as well as the results of tests performed to characterize physical conditions and potential paths of fluid communication within the reservoir. Figure 3 shows the relationship of the analog and hard geological data, and the historical, performance, and well test data.

Hard, Soft, & Historical Data

Hard geological data consist of either remotely measured properties or measurements made on reservoir samples.

Remotely measured data include seismic, electromagnetic surveys, satellite imagery, aerial photography, and surface geochemical analysis. Remote data collection can also include data gathered at the wellbores using wireline tools.

Analyses of rock and fluid samples also provide important information. The analyses should include determinations of rock-fluid compatibility and injected fluid compatibility with reservoir fluids. Relative permeability measurements and laboratory core floods should be performed at conditions of reservoir pressure and temperature, if possible.

One source of soft (analog) data is the examination of similar reservoirs, with nearby reservoirs in the same basin and play being the best models. Outcrops of depositionally, diagenetically, and/or tectonically similar formations also contribute good reservoir information. In many cases, modern environment depositional analogs are good sources of information on sedimentary architecture, as well as type and scale of depositional heterogeneities.

Reservoir history can also be an important and economical source of data. Knowing the completed intervals for each well, as well as how the reservoir evolved, helps one determine which zones may have been inadequately swept by previous waterfloods. Access to a detailed history of drilling practices, completion practices, stimulation practices, and general operational procedures helps one anticipate not only the paths that fluids may have taken in the reservoir in the past, but also the changes that development and operational activities may have had on the reservoir over its lifetime.

Tests performed at wellbores can give insight into the size of reservoir compartments, the interconnectivity between such compartments, and the ease of fluid flow in the reservoir, particularly between specific wells. Pressure transient tests, tracer tests, and spinner and temperature surveys are the most commonly used tests.

In actual projects, operators are often limited by what is available and within their experience. Indeed, it is the skillful integration of the material at hand that yields success. Table 1 shows the variety of data used by different Class projects.

Class Reservoir Examples

The **Diversified Class I** project in the Sooner Unit, Denver Basin, Colorado, used 3-D seismic correlated with electric log petrophysical properties. Results showed that heterogeneity dictates the use of unconventional patterns and spacing for successful waterflood optimization. Incremental oil recovery due to the project is 305,000 bbl, and recovery increased from 15% to 20% of original oil in place (OOIP).

The **Laguna Class II** project in Foster and South Cowden fields, West Texas, used seismic attributes to delineate porosity trends leading to infill drilling and recompletions.

In the **Luff Exploration Class II** project, North Sioux Pass and North Buffalo fields, North and South Dakota and Montana, analysis of 2-D and 3-D seismic indicates reservoir compartmentalization by faults and porosity variation. Targeted infill, lateral recompletions in cased wells, and horizontal wells are being considered based on the reservoir characterization.

Lomax Exploration Class I, Monument Butte Unit, Utah, used FMI logs to discern that fractures occur frequently throughout the reservoir interval. Data on pervasive fracturing and lithologic heterogeneity aided the evaluation of each sedimentary unit for waterflood potential. Also, MRI logs were run on five wells to determine movable oil and water. In a well which showed no potential by conven-

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Table 1 Examples of data types used in the Class projects

Integrated Reservoir Model

Geological Model: Hard Data		Geological Model: Soft (Analog) Data		Physical Model: Historical Data	
Seismic and Related		**Outcrops**		**Production/Injection/Pressure**	
Diversified	Class I	Univ. of Tulsa	Class I	Fina	Class I
Laguna	Class II	BEG Univ. of Texas	Class III	City of Long Beach (mid-term)	Class III
Luff	Class II			Univ. of Utah	Class III
Wireline Logs					
Lomax	Class I				
City of Long Beach	Class III				
ARCO	Class III				
Rock and Fluid					
City of Long Beach (near-term)	Class III				

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tional logs, MRI showed good porosity and permeability. Completion and flow testing proved an oil bearing zone which has produced more than 241,768 bbl of incremental oil.

In the **City of Long Beach Class III**, Wilmington Field, California, near-term heavy oil project, wells are being logged through casing with calibrated pulsed acoustic tools to identify zones with high residual oil saturation. The design for recompletions calls for short and ultra-short-radius horizontal techniques.

ARCO Western Energy's Class III project has used highly integrated reservoir characterization, including advanced logging techniques such as FMI, to identify edge-of-fan fractured and uncontacted targets for slant well drilling in Yowlumne Field, California.

Rock and fluid sample analysis plays an important part in the second **City of Long Beach Class III** Wilmington Field mid-term project. Advanced reservoir characterization and laboratory analysis of interaction between reservoir rocks and steam were performed prior to implementing a pilot demonstration. For details, see the story on page 1.

The **University of Tulsa Class I** project, Glenn Pool Field, Tulsa, Oklahoma, used outcrop studies of the producing formation as an aid to predicting large-scale architecture. The types, scales, vertical successions, and relative orientation of sedimentary bodies located between wells in their analog subsurface reservoir were compared. The results were used to develop a recompletion strategy yielding a 200% increase in oil production from the pilot area.

The **Bureau of Economic Geology, University of Texas, Class III** project is in the Geraldine Ford and West Ford fields in the Delaware Basin of West Texas. Reservoir architecture derived from outcrops is being combined with 3-D seismic data and subsurface information to design geologically optimized producer and injector well patterns for an anticipated polymer flood or CO_2 flood.

The **Fina Class II** project operates in the North Robertson Unit of West Texas. A novel use of decline curves and integration with numerous other data sources were used to define infill targets. The incremental production resulting from the completion of 11 of the 14 proposed producing wells is 800 BOPD above previous rates and represents an 18% increase.

The **University of Utah Class III** project is in the Pru Fee property of the Midway-Sunset Field, California. In many California reservoirs (particularly those in diatomites) such as Midway-Sunset, Lost Hills, and Belridge, waterflooding must replace voidage caused by production to avoid surface subsidence and possible wellbore and formation damage.

Steps for Optimizing Waterfloods

Now that some practical examples show how the integrated reservoir model has been used effectively, you may be interested in applying the technique to your own project. Follow these general steps to optimize waterflooding using the integrated reservoir model:

- Determine the size of the recovery target and the specific location
- Determine the best geometrical arrangement of injection and production points (involves both areal and vertical considerations)–simulation is a valuable tool here
- Determine how much water, where it is needed, and what kind/condition of water (contaminants) is acceptable (simulation helps here also)
- Continue to monitor the operations by collecting performance data for future optimization

Of course, one's approach to waterflood optimization is always strongly influenced by the resources available:

- Capital to invest in reservoir characterization and implementation of new wells
- Available manpower and skills to perform the necessary tasks
- Familiarity with the technologies to select those best for the specific reservoir

Still, keep in mind that the entire reservoir does not have to be considered at once. A pilot implementation is a good, practical approach when risks are involved. A pilot implementation is a proactive test of the results of optimizing waterflooding–and a way to manage the risks of trying new ideas and technologies.

CALENDAR

AUGUST

Aug. 24–27, Rocky Mountain Section AAPG, Denver, Colorado:
- "Characterization of Red River Reservoirs from 3-D Seismic at Cold Turkey Creek Field"; Luff, Class II
- "Heron North Field, Navajo Nation, San Juan County, Utah: a Case Study for Small Calcarenite Carbonate Buildups"; Utah Geological Survey, Class II; in Session, "Oil and Gas Opportunities under Indian Lands"
- Bluebell Field (Class I), Paradox Basin (Class II), and Midway-Sunset (Class III); University of Utah projects to be exhibited at the Utah Geological Survey booth

SEPTEMBER

Sept., Delaware Basin Workshop to be held in New Mexico, date to be announced; BEG, Univ. of Texas at Austin, Class III.

Sept., *World Oil* will have an article on the West Hackberry Tertiary Project; Amoco, Class I.

Sept. 9, West Hackberry Tertiary Project Workshop, Louisiana State University; Amoco, Class I.

Sept. 17–18, SPE Horizontal Well Conference, Panel discussion on case histories. To include S. Cowden Field project; Phillips, Class II.

Sept. 18, Workshop on Michigan Basin; Grand Rapids, Michigan; Michigan Tech Univ., Class II.

Sept. 26–27, AAPG Eastern Regional, Lexington, Kentucky:
- "Recovery of Bypassed Oil in the Dundee Formation Using Horizontal Drains"; Michigan Tech, Class II
- "Field Demonstration of the Ability of In-Situ Microorganisms in the Oil-Bearing Formations to Modify Waterflooding Profiles"; North Blowhorn Field, Alabama, Hughes Eastern, Class I

Sept. 26, Workshop, Petroleum Recovery Center, Hobbs, New Mexico, Reservoir Characterization of Nash Draw Field; New Mexico, Strata, Class III.

OCTOBER

Oct., Delaware Basin Field Trip, Geraldine Ford & Ford West Fields, starting from Midland, Texas, date to be announced; BEG, Univ. of Texas at Austin, Class III.

Oct. 5–8, SPE Annual, San Antonio, Texas:
- "Characterization as a risk reduction tool at the Nash Draw Pool"; Strata, Class III
- "Fractured Characterization based on orientated horizontal core from the Spraberry Trend Reservoir: a Case Study"; Parker and Parsley, Class III
- "Integration of Petrophysical and Geological data with Open Hole Logs for Identification of Naturally Fractured Spraberry Pay Zones"; Parker and Parsley, Class III
- "Using the Internet to Provide Oil and Gas Reservoir Information"; University of Kansas, Class II
- West Hackberry Tertiary Project; Amoco, Class I

Oct. 29–30, FDD Workshop: The Bartlesville Play, Bartlesville/Tulsa, Oklahoma, area, Oklahoma Geological Survey, Class I.

Oct. 30–31, West Texas Geological Society, Midland, Texas:
- Geraldine Ford and Ford West Fields; BEG, Univ. of Texas at Austin, Class III
- Foster and S. Cowden Fields, Geophysical Inversion; Laguna, Class II
- Foster and S. Cowden Fields, progress report; Laguna, Class II

Oct.–Nov., Yowlumne Field, California, Core Workshop, date to be announced; ARCO, Class III.

NOVEMBER

Nov. 12, FDD Workshop: The Bartlesville Play; Norman, Oklahoma, Postal Training Center; Oklahoma Geological Survey, Class I.

ANNOUNCEMENTS

The Class Act newsletter is changing from a quarterly to a biannual newsletter with this issue.

DOE Bartlesville Project Office has been renamed the National Petroleum Technology Office. The office has relocated to Tulsa, Oklahoma. The new street address is:

One West 3rd Street
Williams Center Tower One, Suite 1400
Tulsa, OK 74103

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AMOCO's Class I West Hackberry Field, Alabama, project will receive *Hart's Oil and Gas World's* Best of the Gulf Coast Award in the Best Advanced Recovery Project Category in August 1997.

Texaco's Class II Huff 'n' Puff project in Central Vacuum Field, New Mexico, has been transferred to the Sundown-Slaughter Unit of Slaughter Field, Texas.

Four Class I projects were completed in 1996:

- Diversified Operating, Sooner Unit Field, Colorado
- Lomax Exploration, Monument Butte Field, Utah
- BEG, University of Texas, Vicksburg Fault Play, Texas
- Columbia University, Eugene Isl. Block 330, offshore Louisiana

Copies of the final reports for the first three are available. Contact Viola Rawn-Schatzinger at 918-337-4341, or fax a request to 918-337-4339.

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